PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : E21B 43/12, 34/06

A1

(11) International Publication Number: WO 99/60247

(43) International Publication Date: 25 November 1999 (25.11.99)

(21) International Application Number: PCT/US99/10703

(22) International Filing Date: 14 May 1999 (14.05.99)

(30) Priority Data:
60/085,588 15 May 1998 (15.05.98) US

(71) Applicant: BAKER HUGHES INCORPORATED [US/US]; 3900 Essex Lane #1200, Houston, TX 77027 (US).

(72) Inventor: TUBEL, Paul, S.; 118 E. Placid Hill, The Woodlands, TX 77381 (US).

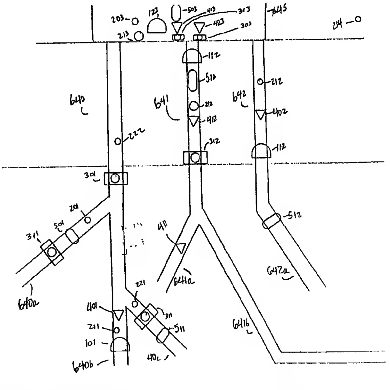
(74) Agents: ROWOLD, Carl, A. et al.; Baker Hughes Incorporated, Suite 1200, 3900 Essex Lane, Houston, TX 77027 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: AUTOMATIC HYDROCARBON PRODUCTION MANAGEMENT SYSTEM

(57) Abstract



The present invention is used to manage oilfield hydrocarbon production from boreholes, specifically to automatically optimize production of fluids from one or more wells in accordance with one or more production goals when presented with readings of the process environment internal to the well process such as temperature, salinity, or pressure, or external to the well process but important nonetheless such as providing economic data, weather data, or any other data relevant to production management. The present invention can automatically sense and adapt to both internal and external process conditions, automatically adjusting operating parameters to optimize production from the wellbore with a minimum of human intervention. The oilfield hydrocarbon production management may be accomplished by systems located downhole, at the surface, subsea, remotely, or from a combination of these systems and includes one or more of the following features: intelligent and non-intelligent well devices such as flow control tools, smart pumps, and sensors; knowledge store databases comprising historical databases, reservoir models, and wellbore requirements; and supervisory control and data acquisition software comprising one or more oilfield hydrocarbon production management goals, one or more process models, and, optionally, one or more goal seeking intelligent software objects.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

AUTOMATIC HYDROCARBON PRODUCTION MANAGEMENT SYSTEM

Background of the Invention

The present invention is a continuation of United States of America provisional patent application 60/085,588, now abandoned.

1. Technical Field

The present invention relates to oilfield hydrocarbon production management systems capable of managing hydrocarbon production from boreholes. The present invention's intelligent optimization oilfield hydrocarbon production management systems sense and adapt to internal and external process conditions, automatically adjusting operating parameters to optimize production from the wellbore with a minimum of human intervention. Oilfield hydrocarbon production management may be accomplished by systems located downhole, at the surface, subsea, or from a combination of these locations. The present invention's oilfield hydrocarbon production management systems include one or more of the following features: intelligent and non-intelligent well devices such as flow control tools, smart pumps, and sensors; knowledge databases comprising historical databases, reservoir models, and wellbore requirements; and supervisory control and data acquisition software comprising one or more oilfield hydrocarbon production management goals, one or more process models, and, optionally, one or more goal seeking intelligent software objects.

2. Background Art

In the current art, production management of hydrocarbons from wells is highly dependent on human operators. However, operation of these wells has become more complex, giving rise to the need for more complex controls, including concurrent controlling of zone production, isolating specific zones, monitoring each zone in a particular well, monitoring zones and wells in a field, and optimizing the operation of wells in real-time across a vast number of optimization criteria. This complexity has placed production management beyond the control of one or even a few humans and necessitates at least some measure of automated controls.

Some current art oilfield hydrocarbon production management systems use computerized controllers to control downhole devices such as hydro-mechanical safety valves. These typically microprocessor-based controllers may also be used for zone control within a well. However, these controllers often fail to achieve the desired production optimization and further require substantial human intervention.

Additionally, current art oilfield hydrocarbon production management systems may use surface controllers that are often hardwired to downhole sensors which transmit data about conditions such as pressure, temperature, and flow to the surface controller. These data may then be processed by a computerized control system at the surface, but such systems still require human intervention and do not provide enforcement of global

optimization criteria, focusing instead, if at all, on highly localized optimization, e.g. for one device.

Some current art oilfield hydrocarbon production management systems also disclose downhole intelligent devices, mostly microprocessor-based, including microprocessor-based electromechanical control devices and sensors, but do not teach that these downhole intelligent devices may themselves automatically initiate the control of electromechanical devices based on adaptive process models. Instead, these systems also require control electronics located at the surface as well as human intervention.

Accordingly, current oilfield hydrocarbon production management systems generally require a surface platform associated with each well for supporting the control electronics and associated equipment. In many instances, the well operator would rather forego building and maintaining a costly platform.

None of the current art disclosing intelligent downhole devices for controlling the production from oil and gas wells teaches the use of electronic controllers, electromechanical control devices and sensors B whether located downhole, surface, subsea, or mixed B together with supervisory control and data acquisition (SCADA) systems which automatically adapt operation of the electronic controllers, electromechanically controllable devices, and/or sensors in accordance with process models and production management goals, or cooperative control of these devices based on a unified, adaptively optimizing system to

automatically enforce system wide set of optimization criteria.

3. Disclosure of Invention

It is therefore an objective of the present invention to provide an improved automatic optimization oilfield hydrocarbon production management system. Accordingly, an improved automatic optimization oilfield hydrocarbon production management system is described.

4. Brief Description of the Drawings

For a further understanding of the nature and objects of the present invention, reference should be had to the following detailed description, taken in conjunction with the accompanying drawings, in which like elements are given the same or analogous reference numbers and wherein:

FIG. 1 is a cross-section of a typical platform indicating several wells, two of which have a plurality of zones;

FIG. 2 is a diagrammatic representation of the present invention's SCADA, including an optional current data source and an optional interrogatable knowledge database;

FIG. 3 is a diagrammatic representation of an intelligent software object; and

FIG. 4 is a diagrammatic representation of intelligent software objects showing flow and hierarchy relationships.

5. Best Mode for Carrying Out the Invention

Referring now to Fig. 1, a cross-section of a typical platform indicating several wells with two of the wells, well 640

and well 641, having a plurality of zones as that term is readily understood by those skilled in the hydrocarbon production arts, the present invention can utilize intelligent and non-intelligent real world devices 100 located at several locations within or around a well.

To illustrate and clarify the present invention, a numbering scheme will be used throughout to identify and distinguish specific devices from generic devices. Accordingly, in the various figures, real world devices in general are referred to generally with the numeric series "100", such as downhole generic real world device 101 in zone 640b of well 640, subsea intelligent real world device 112 in well 641, or surface non-intelligent real world device 123 at surface platform 645. Real world devices 100 include specific devices that are referred to generally as follows: sensors indicated by the numeric series "200," controllable devices by the numeric series "300," injection devices by the numeric series "400," and fluid processing devices by the numeric series "500." In general, the present invention's sensors 200 are capable of providing sensed information about the state of the process to be controlled as well as about the state of other real world devices 100 such as controllable devices 300 or even other sensors 200. Controllable devices 300 may include flow control devices familiar to those skilled in the hydrocarbon production arts and include valves, pumps, and the like. Injection devices 400 may include surface

injection devices 403 such as steam, gas, and water injection devices; downhole injection devices 401 such as downhole oil/water separation devices; and/or a combination thereof. Fluid processing devices 500 may include mechanical or phase separators and/or chemical delivery systems at various locations in or at a well.

For all the numeric series above, a middle digit of "1" indicates an intelligent real world device and a middle digit of "2" indicates a non-intelligent real world device. A middle digit of "0" indicates a generic real world device which can be either an intelligent real world device or a non-intelligent real world device. As used herein, intelligent real world device 110 includes at least one processor unit and computer memory associated with the processor unit. The processor unit may be a general purpose microprocessor or may be any another processing unit, including specialized processors such as those commonly referred to as an ASIC. The computer memory may be volatile, such as random access memory (RAM), changeable such as flash memories, or non-volatile such as read only memory (ROM) or optical memory. Intelligent real world devices 110 may include intelligent well devices and/or robotic devices as well as more traditional controllers.

As opposed to the prior art, real world devices 100, and especially intelligent real world devices 110, may be located downhole, at the surface of the well, subsea, remotely, or a combination of these locations. Therefore, in the discussions

which follow and in the various drawings, an ending digit of "0" in a numeric series indicates a real world device 100 which can be located anywhere. A real world device 100 located downhole will have an ending digit of "1", a real world device 100 located subsea will have an ending digit of "2", a real world device 100 located at the surface (including above or at the sea's surface) will have an ending digit of "3", and a real world device 100 located remotely from the well will have an ending digit of "4". Thus, in the discussion herein below and in the various figures, reference to a generic device, e.g. sensor 200, may be shown in the figure as a generic device at a specific location, e.g. downhole generic sensor 201 in zone 640a of well 640, or a specific device in a specific location, e.g. intelligent downhole sensor 211 located in zone 640b of well 640 or subsea non-intelligent sensor 222 located in well 640.

Referring now to both Fig. 1 and Fig. 2, a diagrammatic representation of the present invention's supervisory control and data acquisition system (SCADA) 10 (not shown in Fig. 1 but shown in Fig. 2), the present invention relates to management of hydrocarbon production from a single production well (e.g. only well 642) or from a group of wells, shown in Fig. 1 as well 640, well 641 and well 642. The various embodiments of the present invention's oilfield hydrocarbon production management system utilize improved SCADA 11 which is capable of intelligent and proactive control of hydrocarbon production. More specifically,

SCADA 11 includes traditional reactive monitoring and control functions as well as one or more production management goals 11c and one or more process models 11d. As opposed to the current art, SCADA 11 executes within one or more intelligent real world devices 110 (e.g. subsea intelligent real world device 112 shown in well 641 or downhole intelligent controllable device 311 shown in zone 640a of well 640) to interact with and proactively control one or more real world devices 100 (e.g. surface non-intelligent controllable device 303 shown in surface platform 645) to automate and optimize hydrocarbon production from a zone or group of zones in one or more wells, a single well, or a group of wells. Real world devices 100 may include sensors 200, such as downhole intelligent sensor 211 in zone 640b; controllable devices 300, such as subsea intelligent controllable device 312 in well 641; injection devices 400, such as downhole generic injection device 401 in zone 640b; fluid processing devices 500 such as downhole generic injection device 501 located in zone 640a; or any combination of these devices. It is understood that any of these real world devices 100, whether intelligent real world devices 110 or not, can be located downhole, subsea, at the surface, remotely or any combination of these locations.

Further, intelligent real world devices 110 may be standalone units, such as traditional controllers embodied in a real world device 100 such as subsea intelligent controllable device 312 located in well 641, may be imbedded within or attached to one or more real world devices 100, for example

intelligent sensors 210 (such as surface intelligent sensor 213 located at surface platform 645), intelligent controllable devices 310 (such as subsea intelligent controllable device 312 located in well 641), injection devices 410 (such as subsea intelligent injection device 412 located in well 641), fluid processing devices 510 (such as downhole intelligent fluid processing device 512 located in zone 642a of well 642), or a combination of the above.

Communication between real world devices 100 may be through any acceptable data communications means 710 (shown in Fig. 2) such as but not limited to radio frequency, light frequency, fiber optics, RS-232, coax, local area networks, wide area networks, or combinations thereof.

Sensors 200 may provide SCADA 11 with sensed data and/or historical data. As used herein, sensed data may include instantaneous data, or real-time data as that term is understood by those skilled in the computer sciences arts, as well as data acquired over some time interval, but sensed data reflect and/or represent at least one parameter of the production process. Historical data, as used herein, may include data from the well(s) being controlled and/or from other wells, and may include data reflective of historical conditions and models about well processes and/or operations in general; data not associated with local wells being controlled by SCADA 11; data regarding production and fluid parameters, reservoir models, and wellbore

requirements; and/or general historical well data. Sensors 200 may also provide SCADA 11 with sensed data reflecting the state of other real world devices 100. Accordingly, sensors 200 may be located and provide sensed data reflective of the process environment downhole, such as downhole generic sensor 201 in zone 640a of well 640; at the surface, such as surface intelligent sensor 213 located in surface platform 645; subsea, such as subsea intelligent sensor 212 located in well 642; remotely, such as remote intelligent sensor 214; or in any combination thereof. Remote sensors 200 may provide SCADA 11 with information about the process environment external to the local well but important to production nonetheless, such as economic data, weather data, or any other data relevant to production management. For example, remote intelligent sensor 214 may comprise a radio transmitter transmitting weather data via satellite (not shown in Fig. 1) to SCADA 11.

As described more fully herein below, an intelligent software object, or ISO, 10 (not shown in Fig. 1) may also be associated with various data sources to act as a "data miner", interrogating historical data for data points congruent or similar to SCADA's 11 sensed data which are therefore useful to SCADA 11.

The present invention lessens if not eliminates the requirement for surface platform 645 to support control electronics and associated equipment as it does not require control electronics located at one particular location, e.g.

surface platform 645. Instead, SCADA's 11 functionality may optionally be distributed across a plurality of intelligent real world devices 110 in one or more distributed processing configurations, each of which is well understood by those skilled in the computer sciences art. Accordingly, SCADA 11 may solely execute in one of the intelligent devices' 110 control electronics or be cooperatively distributed between a plurality of intelligent real world devices 110 located within or distributed between in any combination of downhole, subsea, surface or even remote locations, e.g. distributed in downhole intelligent fluid processing unit 511 located in zone 640c of well 640 and downhole intelligent sensor 211 located in zones 640b of well 640.

Further, whereas current art SCADA 11 software is reactive and limited to monitoring sensors for alarm conditions and proceeding to shut down a process when alarm conditions arise, SCADA 11 adaptively utilizes one or more process models 11d of the production process, including models of the well(s) such as well 640, well 641, and well 642, their zone(s) such as zones 640a, 640b, 640c, 641a, and 641b, and real world devices 100 in addition to one or more higher level production management goals 11c to proactively control and manage hydrocarbon production. SCADA 11 may therefore be configured to respond to conditions associated with a single well such as well 640 as a whole, including its zones such as zone 640a, zone 640b, and zone 640c; conditions associated with one or more zones in a single well,

such as only zone 640a or only zone 640a and/or zone 640b; conditions associated with one or more zones in a plurality of wells, such as zone 640a and zone 641a; or conditions associated with an entire oilfield such as well 640, well 641 and well 642. These conditions may include conditions internal to a given well such as downhole temperature, pressure, and/or fluid conditions; process conditions external to a given well, e.g. field conditions; and non-process conditions, e.g. economic conditions.

Using data from its various sensors 200, e.g. downhole generic sensor 201 or downhole intelligent sensor 211, SCADA 11 monitors process parameters (such as downhole pressure, temperature, flow, gas influx, etc.) and automatically executes control instructions to modify the operating parameters of its various sensors 200, controllable devices 300, injection devices 400, and fluid processing devices 500 in accordance with its process models 11d and production management goals 11c to optimize hydrocarbon production from the well.

SCADA 11 may also adapt its process models 11d based on actual, current conditions including remote conditions, past or historical conditions and models, and/or actual responses to SCADA 11 commands. Current conditions may include instantaneous as well as substantially contemporaneous events. Therefore, as further opposed to the current art that merely monitors for and/or reacts to alarm conditions, SCADA 11 adaptively controls downhole, surface, and subsea devices, whether or not in alarm, in accordance with SCADA's 11 analysis of its models and data

from a variety of sources, including external data sources, with a minimum of human intervention.

Referring now generally to Fig. 3, a diagrammatic representation of an ISO 10, in a preferred embodiment SCADA 11 may further comprise one or more ISOs 10. ISOs 10 provide a variety of functions useful in control and/or optimization applications and may be connected or grouped together in a variety of ways, more fully described herein below.

An ISO 10 comprises internal software objects, as that term is understood by those skilled in the computer programming arts. ISO's 10 internal software objects may be configurably enabled, disabled, or not configured at all, and may include expert system objects 12 capable of utilizing one or more rules knowledge databases 13, which contain crisp logic rules 14 and/or fuzzy logic rules 16; adaptive models objects 20 which may use multiple, concurrent, differing modeling methodologies to produce adaptive models which "compete" in real-time with each other adaptive model within ISO 10 to predict a real-time process outcome based on current, past, and predicted process parameters; predictor objects 18 which select from among the various competing adaptive model of the adaptive models objects 20 that adaptive model which bests predicts the measured real-time process outcome; optimizer objects 22 which decide optimum parameters to be used by an ISO 10 for a given state of the process, calculation, or component to be optimized; communication translator objects 26 which may handle communications between an

ISO 10 and anything outside ISO 10; and ISO sensor objects 25 (which are different than sensors 200) which, in part, act as intelligent data storage and retrieval warehouses and data managers for the state(s) of the controlled process, including the state(s) of the control variables for the process. Sensor objects 25, expert system objects 12, predictor objects 18, adaptive models objects 20, and optimizer objects 22 work together within ISO 10 to find, calculate, interpret, and derive new states for the control variables that result in the desired process state(s) or achieve process management goal(s) 32. For example, expert system objects 12, optimizer objects 22, predictor objects 18, and adaptive models objects 20 communicate and configurably interact with each other adaptively, automatically changing each other's behavior in real-time, including creating and deleting other internal software objects. Further, optimizer object 22 may modify expert system objects' 12 rules knowledge bases 13, and expert system object 12 may modify optimizer objects' 22 optimum goals to be sought.

Referring now to Fig. 4, a diagrammatic representation of ISOs 10 in flow and hierarchical relationships, ISOs 10 can model and represent any device or group of devices including sensors 200, controllable devices 300, fluid processing devices 400, injection devices 500, or any combination thereof. ISOs 10 can also model and represent more abstract processes such as a single zone like 640a, a group of zones such as 640a and 640b, an entire well such as well 640, or an entire field such as wells 640, 641,

and 642. To accomplish these models and representations, two or more ISOs 10 may be configured in either "flow relationships" that model, or representationally correspond to, the flow of the material and/or information which is to be controlled, and/or "hierarchical relationships" that define the prioritization and scope relationships between ISOs 10 or groups of ISOs 10, e.g. between that which is being modeled. ISOs 10 configured in this manner therefore cooperatively represent the process to be controlled.

Referring now to Fig. 1 and Fig. 4, as an example ISO 610a may represent zone 640a of well 640, as shown in Fig. 1, as an abstract, aggregate process and ISO 610b may represent zone 640b of well 640 as an abstract, aggregate process. ISO 610c may represent controllable device 301 located in well 640 above zones 640a and 640b, and data therefore "flow" from ISO 610a to and from ISO 610c, and from ISO 610b to and from ISO 610c to reflect and model the flow of hydrocarbons from those zones into well 640.

Further, ISO 610d may be a "hierarchy" ISO 10 and represent well 640 as an aggregate whole, and ISO 610e may be another "hierarchy" ISO 10 representing well 641 as a whole. Finally, "hierarchy" ISO 610f may represent the field in which well 640 and well 641 are both located. Within ISO 610f, each of ISO 610d and 610e can concurrently be "flow" ISOs 10 as well, representing, for example, the flow of hydrocarbons from each well into surface platform 645.

ISOs 10 are therefore very flexible and powerful in their modeling flexibility. An ISO's 10 rules, goals, and optimization criteria may be initialized and/or modified configurably or in real-time by either the ISO 10 itself, other ISOs 10, human intervention, or a combination thereof. For example, in Fig. 4, ISO 610c can modify each of ISO 610a and 610b to change their production management goals 10c based on ISO's 610c production management goals 10c. Optimization may therefore be achieved through the cooperation between an ISO's 10 internal software objects as well as between ISOs 10 configured to represent an entire process.

Referring back now to Fig. 1 and Fig. 2, given its one or more process models 11d, one or more production management goals 11c, and optionally one or more ISOs 10, SCADA 11 further differs from the prior art by proactively using its one or more process models 11d B which may further comprise several models of sub-processes and well devices B to issue control commands which impact on and modify operating parameters for real world devices 100, including controllable devices 300, to control production from a wellbore such as well 640 to accomplish SCADA's 11 production management goals 11c. Alternatively, SCADA 11 can proactively to issue control commands using inputs from its sensed and historical data alone. SCADA 11 therefore permits fully automatic, concurrent, complex operation and control of single and/or multi-zone production including isolating specific zones such as 640a, 640b, or 640c; monitoring each zone in a

particular well such as well 640; monitoring zones and wells in a field such as well 640, well 641, and well 642; and optimizing the operation of one or more wells across a vast number of optimization criteria. Accordingly, SCADA 11 can provide for enforcement of optimization criteria with a more global scope rather than being limited to narrowly focusing on highly localized optimization, e.g. for one real world device 100. In doing so, SCADA 11 is better equipped to handle complex operations than human operators. Although human intervention may modify or override SCADA's 11 management of hydrocarbon production, SCADA's 11 ability to rapidly and adaptively react to complex and changing conditions affecting production with a minimum of human intervention allows SCADA 11 to automatically detect and adapt to varying control and communication reliability while still achieving its important control operations. Accordingly, SCADA 11 enhances safe operation of the well, both from human worker and environmental aspects.

In communication with real world devices 100 such as sensors 200 (e.g. generic downhole sensor 201), controllable devices 300 (e.g. downhole intelligent sensor 311), injection devices 400 (e.g. subsea generic injection device 402), and fluid processing devices 500 (e.g. downhole generic fluid processing device 501), SCADA 11 manages hydrocarbon production from one or more wells according to its process models 11d and the conditions of which it is aware, adaptively modifying its process models 11d to more fully correspond to actual responses to given commands

when compared to predicted responses to given commands, thus adaptively and automatically accomplishing its set of one or more production management goals 11c. SCADA 11 can also manage hydrocarbon production from one or more wells according to its sensed and historical data. SCADA 11 executes in one or more intelligent real world devices 110, including downhole intelligent real world devices 111, subsea intelligent real world devices 111, surface intelligent real world devices 112, remote intelligent real world devices 114 (not shown in Fig. 1), or any combination thereof. SCADA's 11 communication can be unidirectional (for example, from downhole non-intelligent sensor 221 in zone 640c of well 640) or bidirectional (for example, to and from intelligent downhole controllable device 311 in zone 640c of well 640).

Referring still to Fig. 1, as is well known in the art a given well may be divided into a plurality of separate zones, such as zone 640a, zone 640b, and zone 640c. Such zones may be positioned in a single vertical well such as well 640 associated with surface platform 645, or such zones may result when multiple wells are linked or otherwise joined together (not shown in Fig. 1). These zones may need to be concurrently monitored and/or controlled for efficient production and management of the well fluids. Accordingly, intelligent real world devices 110 and non-intelligent devices 120 can co-exist within a single zone, multiple zones of a single well, multiple zones in multiple wells, or any combination thereof. At least one real world device

100 will be an intelligent real world device 110, e.g. an intelligent sensor 210 such as downhole intelligent sensor 211 located in zone 640b of well 640 or an intelligent controllable device 310 such as downhole intelligent controllable device 311 located in zone 640a of well 640.

It is further contemplated that one or more ISOs 10 may also be resident in one or more intelligent real world devices 110 such as an intelligent sensor 211 or an intelligent controllable device 311. SCADA 11 may communicate with one or more ISOs 10, and may use ISOs 10 to adaptively and cooperatively control the real world devices 110 in which ISOs 10 reside or which ISOs 10 model.

In a further alternative configuration, SCADA 11 may further utilize data from an interrogatable knowledge database 11e, comprising historical data about well operations, and/or current data source 700 which is not associated with local wells being controlled by SCADA 11, e.g. wells 640, 641, or 642. For example, SCADA 11 could obtain current data from remote intelligent sensor 214. These data could include well maintenance schedules, weather reports, price of hydrocarbons, and other non-well data which do not arise from but may impact optimization of hydrocarbon production from a well. As a further example, SCADA 11 may be programmed with a process model 11d which includes a model of tanker vessel availability and its impact on hydrocarbon production for a subsea well, e.g. well 640. SCADA 11 may then adjust hydrocarbon production using non-well data such as weather

data communicated to SCADA 11 which may impact the arrival schedule of a tanker vessel.

In a like manner, SCADA 11 may utilize interrogatable knowledge database 11e to aid in optimization of hydrocarbon production. Interrogatable knowledge database 11e may include historical data, descriptions of relationships between the data, and rules concerning the use of and relationships between these data and data from a single well such as well 640, from a plurality of wells in a field such as wells 640 and 641, and/or from accumulated well production knowledge. Interrogatable knowledge database's 11e historical data may therefore comprise data regarding production and fluid parameters, reservoir models, and wellbore requirements, whether from well 640, the field in which the particular downhole well is located, or from general historical downhole well data. SCADA 11 has the ability to interrogate knowledge database 11e and integrate its data into SCADA's 11 adaptive modification of its predictive models, giving SCADA 11 a broader base of data (historical, current, and predicted) from which to work.

Further, in each configuration described herein above, one or more controllable devices 300 or sensors 200 may be operatively associated with one or more self-propelled robotic devices (not shown in the figures). These robotic devices may be permanently deployed within a downhole well and mobile in the well and its zones. Additionally, these robotic devices may also be configured to traverse zones within a well such as well 640;

wells in a field such as wells 640, 641, and 642; or exit the well altogether for other uses such as subsea or surface uses or retrieval. SCADA 11 may be configurably distributed in one or more robotic devices because they are intelligent real world devices 110. For example, robotic devices may be viewed by SCADA 11 as controllable devices 310 like other controllable devices 300 described herein above and controlled accordingly.

It may be seen from the preceding description that an automatic optimization oilfield hydrocarbon production management system has been described and provided.

It is noted that the embodiment of the automatic optimization oilfield hydrocarbon production management system described herein in detail for exemplary purposes is of course subject to many different variations in structure, design, application and methodology. Because many varying and different embodiments may be made within the scope of the inventive concept(s) herein taught, and because many modifications may be made in the embodiment herein detailed in accordance with the descriptive requirements of the law, it is to be understood that the details herein are to be interpreted as illustrative and not in a limiting sense.

6. <u>Industrial Applicability</u>

The present invention is used to manage oilfield hydrocarbon production from boreholes, specifically to automatically optimize production of fluids from one or more zones in one or more wells in accordance with one or more

production goals with a minimum of human intervention when presented with sensed readings of the process environment internal to the well process such as temperature, salinity, or pressure, and/or external to the well process but important nonetheless such as providing economic data, weather data, or any other data relevant to production management.

CLAIMS

I Claim:

Claim 1. An apparatus for management of hydrocarbon production from a downhole well comprising:

a production management system having supervisory control and data acquisition software, a production management goal, and a software model of a controllable process;

an intelligent device comprising a processor unit and memory associated with said processor unit in which said supervisory control and data acquisition software executes;

a sensor, capable of communicating sensed data representative of at least one parameter of hydrocarbon production processing, in communication with said production management system; and

a controllable device, capable of responding to control commands and controlling at least one production process variable influencing said hydrocarbon production processing, in communication with said production management system

wherein said sensor communicates data to said production management system, said production management system communicates with said controllable device, and said supervisory control and data acquisition software utilizes said software model and said data from said sensor to control said controllable device to manage hydrocarbon production in accordance with said production management goal.

Claim 2. The apparatus of Claim 1 further comprising an intelligent software object in communication with said production management system, wherein said intelligent software object further comprises:

a plurality of internal software objects, said plurality of internal software objects being selected from the group of expert system software objects, adaptive models software objects, predictor software objects, optimizer software objects, and combinations thereof wherein said expert system software object is in communication with said optimizer software object and may modify said optimizer software object's behavior,said expert system software object is in communication with said predictor software object and may modify said predictor software object's behaviosaid expert system software object is in communication with said adaptive models software object and may modify said adaptive models software object's behavior,

said optimizer software object is in communication with said expert system software object and may modify said expert system software object's behavior,

said optimizer software object is in communication with said predictor software object and may modify said predictor software object's behavior, and

said optimizer software object is in communication with said adaptive models software object and may modify said adaptive models software object's behavior

whereby

said plurality of internal software objects exhibit aggregate goal seeking behavior.

Claim 3. The apparatus of Claim 1 wherein said sensor is selected from the group of non-intelligent sensors located downhole, intelligent sensors located downhole, non-intelligent sensors located at the surface, intelligent sensors located at the surface, non-intelligent sensors located subsea, and intelligent sensors located subsea.

Claim 4. The apparatus of Claim 1 wherein said controllable device is selected from the group of non-intelligent controllable devices located downhole, intelligent controllable devices located downhole, non-intelligent controllable devices located at the surface, intelligent controllable devices located at the surface, non-intelligent controllable devices located subsea, and intelligent controllable devices located subsea.

Claim 5. An apparatus for management of hydrocarbon production from a downhole well comprising:

a production management system having supervisory control and data acquisition software;

an intelligent device comprising a processor unit and memory associated with said processor unit in which said supervisory control and data acquisition software executes;

a source of historical data relevant to said downhole well, capable of communicating said historical data, in

communication with production management system; a sensor, capable of communicating sensed data representative of at least one parameter of hydrocarbon production processing, in communication with said production management system; and

a controllable device, capable of responding to control commands and controlling at least one production process variable influencing said hydrocarbon production processing, in communication with said production management system

wherein

said production management system utilizes said sensed data, and said historical data to control said controllable device to manage said hydrocarbon production.

Claim 6: The apparatus of Claim 5 further comprising a current data source wherein said current data source provides said production management system with substantially current data other than said sensor data.

Claim 7. A method of management of hydrocarbon production from a downhole well for an apparatus comprising supervisory control and data acquisition software, an intelligent device comprising a processor unit and memory associated with said processor unit in which said supervisory control and data acquisition software executes, a sensor in communication with said supervisory control and data acquisition software, and a controllable device capable of controlling at least one production process variable

influencing said production where said controllable device is in communication with said supervisory control and data acquisition software, said method comprising the steps of:

providing said supervisory control and data acquisition software with a production management goal and a software model of a controllable process;

providing sensed data to said supervisory control and data acquisition software from a sensor, said sensed data being representative of at least one parameter of processing production from said downhole well; and

having said supervisory control and data acquisition software utilize said software model of a controllable process and said data from said sensor to control said controllable device thereby achieving said management of hydrocarbon production in accordance with said production management goal.

Claim 8. A method of management of hydrocarbon production from a downhole well for an apparatus comprising supervisory control and data acquisition software, an intelligent device comprising a processor unit and memory associated with said processor unit in which said supervisory control and data acquisition software executes, a sensor in communication with said supervisory control and data acquisition software, a source of historical data in communication with said supervisory control and data acquisition software, and a controllable device capable of controlling at least one production process variable thereby influencing

said production where said controllable device is in communication with said supervisory control and data acquisition software, said method comprising the steps of:

providing said supervisory control and data acquisition software with data from said historical data source relevant to said well;

providing said supervisory control and data acquisition software with data from said sensor representative of at least one parameter of said management of hydrocarbon production; and

having said supervisory control and data acquisition software utilize said data from said historical data source and said data from said sensor to control said controllable device and thereby control at least one production process variable to influence said management of hydrocarbon production.

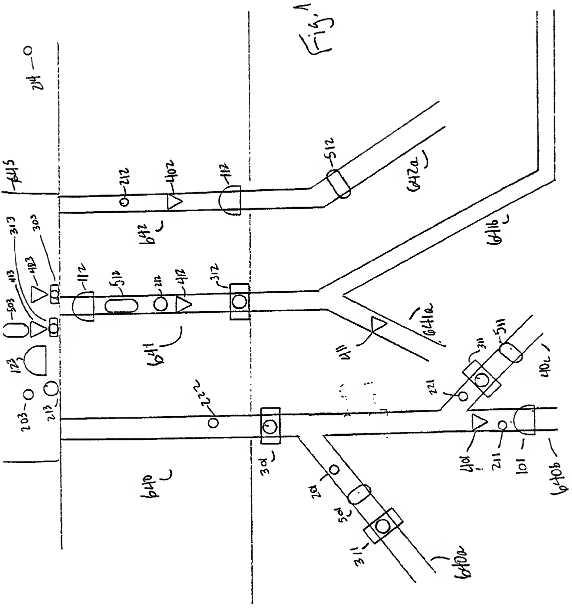

645
214
203
213
123
503
413
403
313
303
112
512
212
402
642
642a
641
511
412
312
641a
641b
411
640
222
301
201
501
311
640a
221
511
640c
401
211
101
640b

Fig. 1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/10703

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 E21B43/12 E21B34/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 676 313 A (RINALDI ROGER E) 30 June 1987 (1987-06-30) column 1, line 59 - column 2, line 39 column 4, line 26-44 claims 1-3,6-9,12 figure 1 ---	1,3-8
A	WO 96 24747 A (BAKER HUGHES INC) 15 August 1996 (1996-08-15) page 9, line 10-19 page 13, line 8-19 page 15, line 10-24 ---	1,5,7,8

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 July 1999	04/08/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schouten, A

2

Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/US 99/10703

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No
A	CLARK E. ROBISON: "Overcoming the Challenges Associated With the Life-Cycle Management of Multi-Lateral Wells: Assessing Moves Towards the "Intelligent Completion"" SPE # 38497,9 September 1997 (1997-09-09), pages 1-8, XP002109728 the whole document ---	1,5,7,8
A	US 3 892 270 A (LINDQUIST ROBERT H) 1 July 1975 (1975-07-01) column 2, line 59 - column 3, line 2 figures 1,2 ---	1,5,7,8
A	WO 97 46793 A (PROTECHNICS INTERNATIONAL INC ;TRAINOR WILLIAM F (US); WANG ZHENYU) 11 December 1997 (1997-12-11) page 3-5 ---	1,5,7,8
A	US 5 706 896 A (MULLINS II ALBERT A ET AL) 13 January 1998 (1998-01-13) column 14, line 13 - column 15, line 22 -----	1,5,7,8

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 99/10703

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 4676313	A	30-06-1987	NONE			
WO 9624747	A	15-08-1996	US	5732776	A	31-03-1998
			AU	4980696	A	27-08-1996
			AU	5022396	A	27-08-1996
			CA	2187422	A	15-08-1996
			CA	2187423	A	15-08-1996
			GB	2302114	A,B	08-01-1997
			GB	2302432	A	15-01-1997
			NO	960518	A	12-08-1996
			NO	960527	A	12-08-1996
			WO	9624751	A	15-08-1996
US 3892270	A	01-07-1975	US	RE30019	E	05-06-1979
WO 9746793	A	11-12-1997	AU	3229597	A	05-01-1998
US 5706896	A	13-01-1998	AU	697668	B	15-10-1998
			AU	5024296	A	27-08-1996
			CA	2187424	A	15-08-1996
			GB	2302115	A	08-01-1997
			GB	2330853	A	05-05-1999
			NO	960517	A	12-08-1996
			WO	9624749	A	15-08-1996
			US	5721538	A	24-02-1998